

Plant Nutrition System of Cereals in Their Sustainable Crop Production

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In the "golden period" of Hungarian agriculture (from the 1960's to the end of the 1980's) mainly cereal production developed dynamically and reached the level of well-developed West-European and North-American countries. This rapid yield increase was based on the extended use of external industrial inputs, among which fertilization was the most important and determining factor. During the above-mentioned 30 year period fertilizer use in Hungary increased from 15 to 250-300 kg/ha NPK. Due to this dynamic fertilizer application - and several other factors (pesticides, fossil energy, machinery hardware, professional knowledge etc) - the yield of different crops (mainly cereals) increased and 2- or 3-times more yield was obtained as compared to the average yields in the early 60's. It should be emphasized that these appropriately applied fertilizer doses (about 250 kg/ha NPK) were not too large amounts in comparison with the crops' demands, Hungary's agroecological conditions and with the fertilization practice in well-developed countries.

As a consequence of economical-financial problems there was a dramatic drop in fertilizer use from the end of the 80's and only about 20-50 kg/ha NPK is being applied nowadays. Unfortunately the level of other agrotechnical factors has also lowered. Low fertilizer doses and low levels of other crop management factors resulted in yield decrease and lower yield-stability. In winter wheat production (Table 1) 4.6-5.5 t/ha was obtained on country average and yield stability was excellent in different cropyears of the 80's (interval of yield fluctuation was 15%). In the 90's wheat yield dropped from 5.2 to 3.1 t/ha, which expresses the low yield stability of this period (interval of yield fluctuation was 49%).

Among the agrotechnical elements of crop production (mainly in cereals [wheat, maize]) fertilization (first of all nitrogen fertilization) plays the main role and has the greatest effect on yield and the manifestation and efficiency of other crop management elements. Other agrotechnical elements can be modi-

Table 1
Yield and yield stability of winter wheat

Year	Yield (kg/ha)	Average yield (kg/ha)	Min. and max. of yield to average, %	Interval of yield fluctuation, %
1981	4580	5048	93-108	15
1982	5140			
1983	4710			
1984	5370			
1985	5120			
1986	4910			
1987	4910			
1988	5450			
1989	5240			
1990	5050	4370	70-119	49
1991	5190			
1992	4070			
1993	3060			
1994	4610			
1995	4240			

fied positively by the application of optimum doses and ratios of nitrogen, phosphorous and potassium fertilizers.

According to Hungarian and international literature the factors influencing the effects of mineral fertilizers are: weather, soil characteristics, water supply, uniformity of the crop and nutrient response of the cultivated plant or variety.

Among agrotechnical elements fertilization is one of the most efficient means of increasing yields. A strong correlation exists between the yields and the quantity of fertilizers used (BOCZ, 1963).

In spite of the varying environmental conditions the specific nutrient demand of winter wheat is not too variable (DUKA et al., 1974; SARKADI, 1975; BOCZ, 1976; LÁNG, 1976).

In the literature related to fertilization a wide range of data can be found on the specific nutrient demand of winter wheat. In most of the cases the optimal species-specific dose of fertilizers varies within the range of 300-500 kg/ha of NPK active agents (LÁNG, 1971; RUZSÁNYI, 1975; BOCZ, 1976; GOLCEVA, 1977; HARMATI & SZEMES, 1977; KOLTAY & BALLA, 1982; JOLÁNKAI, 1982; PLESÁKOVA et al., 1983).

BALKO & RUSSEL (1980) suggest that comparisons should be made between hybrids at such fertilizer rates that ensure the highest yields. On the other hand, NAGY (1995) claims that hybrids can be compared effectively in multi-stage fertilizer trials where the yields on non-fertilized plots will properly show the

natural nutrient extracting ability of hybrids. According to MENYHÉRT (1985) and MENYHÉRT et al. (1980) there is also strong correlation between nutrient supply and crop density.

IRVINE (1963) states that the method and dose of fertilization should not be decided upon on the basis of maximum achievable yields but solely on the basis of profitability. According to DEBRECZENI (1980) the upper limit of fertilization must be determined by the optimum level of efficiency deriving from extra yields.

In recent years the variety assortment of winter wheat has grown in Hungary and practical farming has stressed the need to work out the variety-specific technology of winter wheat.

The most important elements of variety-specific technology of winter wheat are fertilization and irrigation. The N fertilizer demand of winter wheat varieties is 120-180 kg/ha (HARMATI, 1982) and 80-160 kg/ha (HERA et al., 1981). JOLÁNKAI (1982) describes 3 different N-requirement groups of winter wheat varieties.

PEPÓ et al. (1989) classified new winter wheat varieties into 4 different groups on the basis of their N-response.

Materials and Methods

The basic total *fertilizer* dose was 158 kg/ha, including 60 kg N/ha, and 1-2-3-4-5-fold amounts of the basic dose were applied with a non-fertilized control. As all *treatments* used the same NPK ratio (1 N : 0.75 P₂O₅ : 0.88 K₂O), the doses are referred to simply by their N content. The trial was set up in strip arrangement with four replications (with a size of 1260 m² each) and there were 6 random fertilizer treatments in each replication. The size of each fertilization plot was 210 m².

Soil characteristics. - The main characteristics of the calcareous chernozem soil with a lowland loess basic layer are as follows: average N and P supply and high K supply (humus content: 2.8-3.0%, total N: 0.14-0.18%, AL-P₂O₅: 130-200 mg/kg, AL-K₂O: 240-280 mg/kg); depth of the humus layer: 70-90 cm; pH (KCl): 6.2; upper limit of plasticity according to Arany (K_A): 43. Microelement deficiency cannot be detected.

The groundwater level is between 6-8 m. The minimum water holding capacity (WHC_{min}) of the soil is 27-29 volume %, its water storage capacity is 275 mm in the 0-100 cm profile and 265 mm in the 100-200 cm profile. The disponible WHC is 157 mm and 150 mm in the 0-100 and 100-200 cm profile, respectively.

To ensure reliability in the evaluation, up-to-date experiment design methods were applied in the planning of our research programme and an improved version of the previously theoretically proven method of BOX & WILSON (1951) was used. Experimental data were evaluated by correlation and

regression analysis (SVÁB, 1981; JOHN, 1971; WINER, 1971). When fitting the regression line the deviations' total sum of squares was minimized. The parameters of the equation were tested with the t-probe. Evaluation was carried out on a 486 DX computer using the 1988 version of the BMDP Statistical Software.

Results and Discussion

In our 20-year-old long-term experiment on chernozem soil the fertilizer response of winter wheat varieties was tested by the Bocz method. Figure 1 shows that there were differences among the cropyears and wheat varieties in the utilization of natural nutrient resources (control treatment) and different fertilizer doses (N = 60, 120, kg/ha + PK treatments).

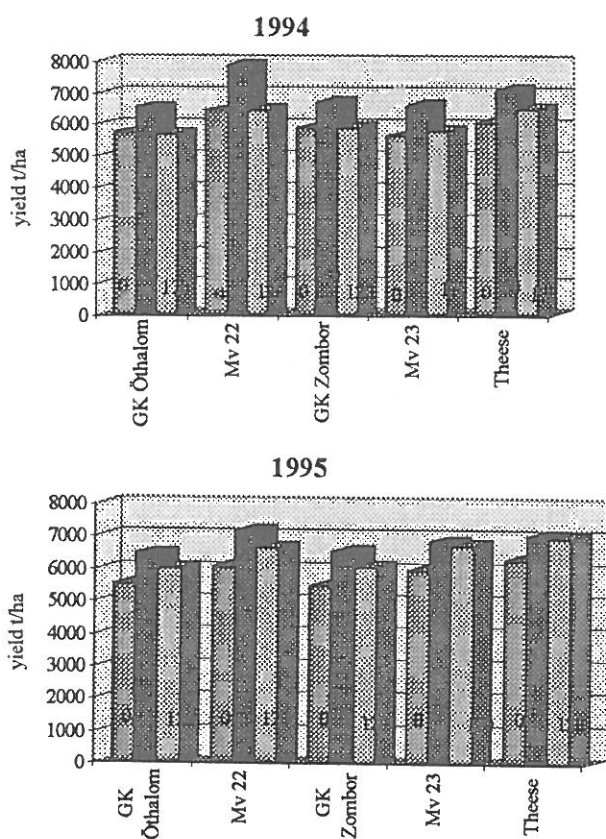


Figure 1
Soil nutrient utilization and fertilization response of different wheat varieties
in 1994 and 1995

In Figure 2 it can be seen that the yield surplus per one unit (1 kg) of NPK fertilizers depended on the winter wheat variety and cropyear. We obtained better yield surpluses with Mv 22, Mv 23 varieties in the 1994 and 1995 crop-years.

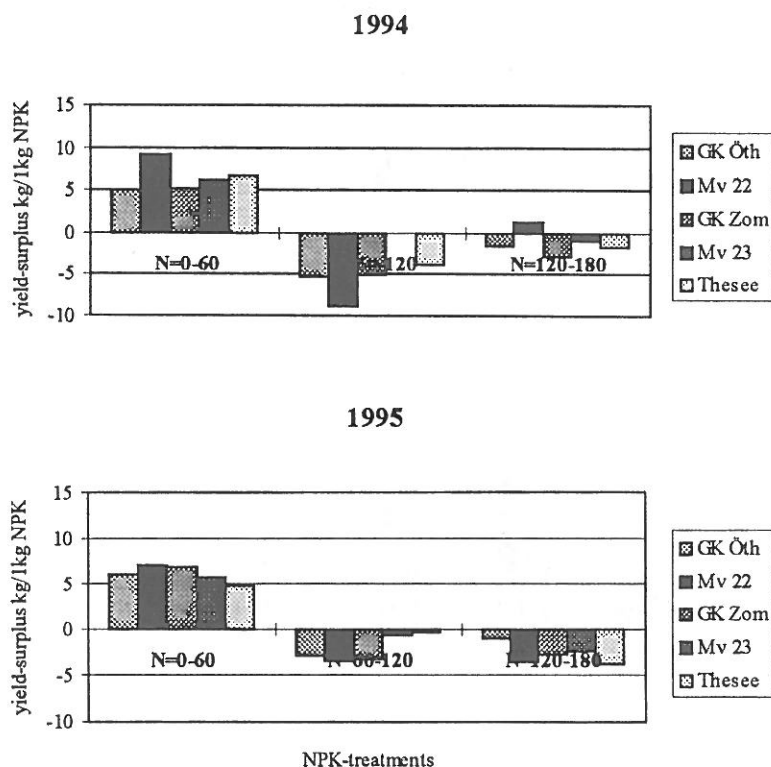


Figure 2
Yield surpluses of wheat varieties per 1 kg NPK fertilizers
(Debrecen, 1994 and 1995)

Appropriate fertilization increases yield stability and the adaptability of crop to ecological stresses. Under our continental conditions water-stress, drought stress is the most frequent and strongest stress factor. Figure 3 shows yield kg's per 1 mm rainfall (calculated with the rainfall of: a) the whole cropyear, b) autumn + winter period, and c) spring + early summer period). Better water utilization efficiency was obtained in the case of optimum fertilizer treatment in all cropyears as compared to the unfertilized control treatment, even on the chernozem soil with excellent hydrophysical properties.

Our twenty-year experimental data proved that there were differences in the fertilizer demands and fertilizer utilization (mainly in nitrogen) of winter wheat

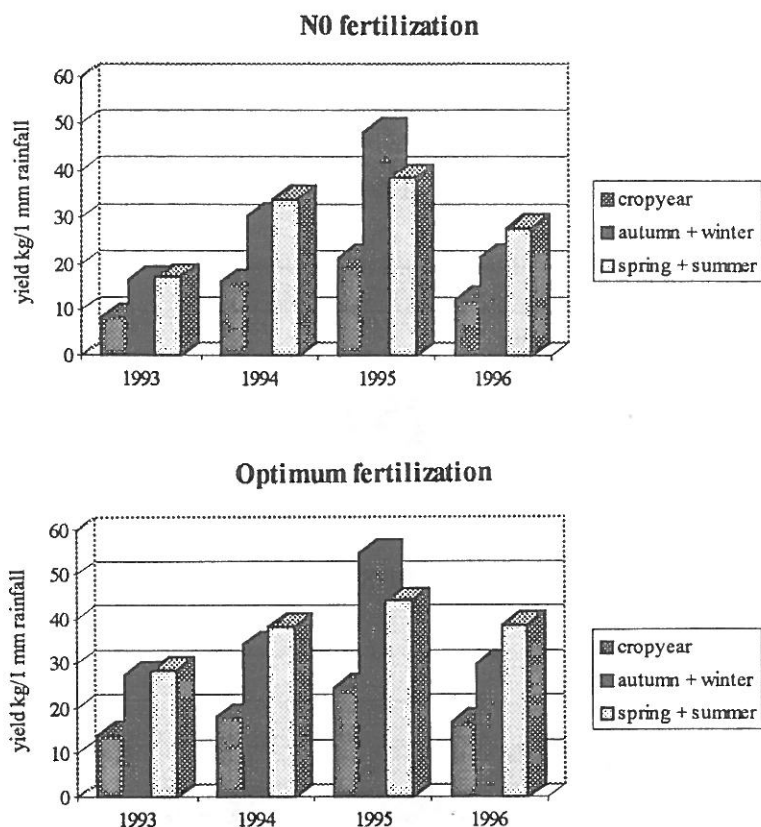


Figure 3

The water utilization of winter wheat in different cropyears

varieties. Some varieties reached maximum yield in $N_{60}+PK$ fertilizer treatment, while several others needed $N_{120}+PK$ to obtain maximum yields (Figure 4).

Based on our long-term trials the winter wheat varieties were divided into 4 types according to their nutrient utilization and fertilizer responses. Fertilizer response of varieties were grouped as follows:

- the natural nutrient utilization of varieties (control yield);
- yield increase per one unit of fertilizer;
- the optimum fertilizer doses for varieties;
- the maximum yield of varieties.

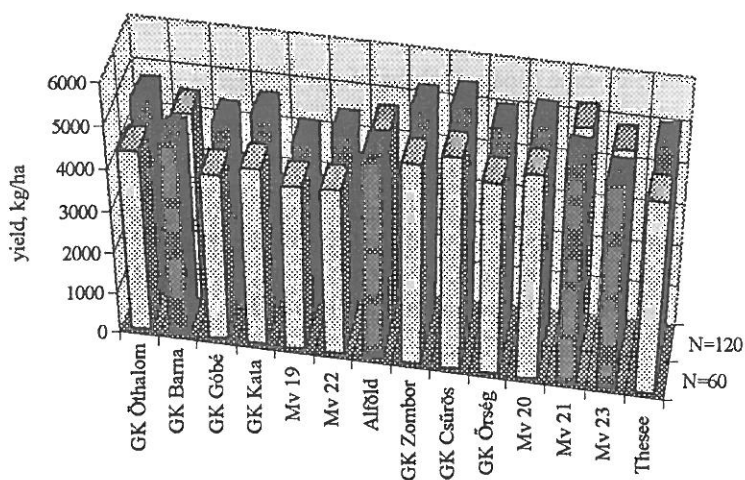


Figure 4
Variety-specific N demand of winter wheat varieties (Debrecen, 1993)

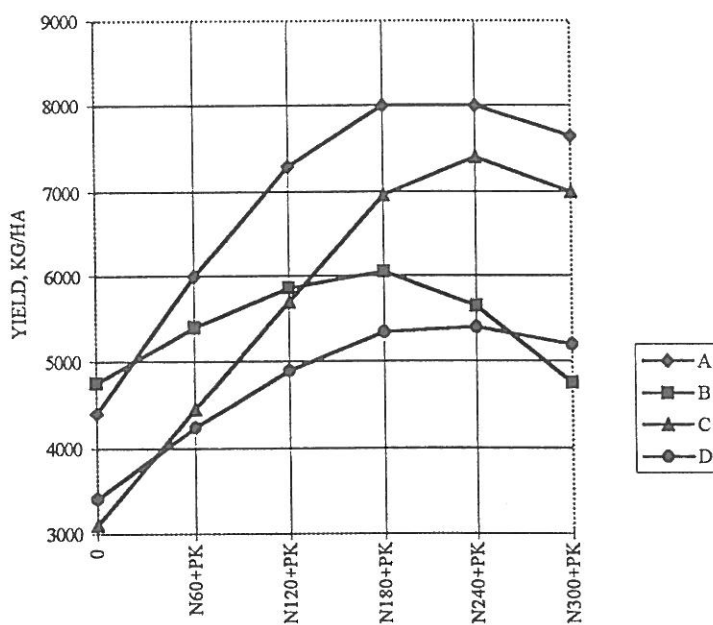


Figure 5
Fertilizer response types of winter wheat varieties (Debrecen)
Type A: up-to-date type which has both extensive and intensive response characteristics, B: traditionally extensive type, C: traditionally intensive type, D: outdated type with the worst fertilizer response characteristics

According to nutrient utilization and fertilization response the varieties were classified into 4 groups (Figure 5):

Type A - up-to-date type which has both extensive and intensive response characteristics;

Type B - traditionally extensive type;

Type C - traditionally intensive type;

Type D - outdated type with the worst fertilizer response characteristics.

Our long-term experiments proved that the differences in fertilizer demand and response (mainly in nitrogen) of wheat varieties were greater in the case of unfavourable ecological and agrotechnical conditions.

Table 2
**Nitrogen optimum of winter wheat varieties of different genotype,
determined by regression-analysis**

Variety	1987	1989
	Agroecological N-opt. (kg/ha)	Agroecological N-opt. (kg/ha)
GK Öthalom	144	115
GK Zombor	106	106
Mv 15	121	110
Jubilejnaja 50	56	94
Width of N-optimum	88	21

Table 2 shows that the optimum N doses of varieties ranged from 56 to 144 kg/ha (interval was 88 kg/ha) in 1987 (in an unfavourable cropyear), while they were between 94-117 kg/ha (interval was 21 kg/ha) in 1989 (in a favourable cropyear).

The effects of fertilization in irrigated and non-irrigated treatments were investigated at six fertilization levels in four replications yearly, using the 4-year yield data of maize (Table 3).

For the evaluation of the fertilization effect regression analysis was used and a quadratic function was fitted. The linear and quadratic values of fertilization were the independent variables and the yield was the dependent one. In each case the significance of the equation and its parameters, too were investigated. With the help of the first derivative of the quadratic equation the maximum of the function as well as the corresponding fertilizer dose was specified. Using the first derivative again, we specified the fertilizer dose and the corresponding yield for the pre-set tangent of the function (10 kg extra yield/1 kg nitrogen fertilizer per hectare).

Table 3
The effect of fertilization on the yield of maize, t/ha

Fertilizer treatment	1990	1991	1992	1993	Average
<i>Without irrigation</i>					
Control	5.387	10.630	5.498	6.802	7.079
1	7.296	13.510	6.328	9.847	9.245
2	8.001	13.715	6.209	10.221	9.537
3	7.807	13.219	6.653	10.582	9.565
4	7.489	12.894	5.539	9.721	8.911
5	7.438	13.031	5.548	9.392	8.852
Average	7.236	12.833	5.963	9.428	8.865
<i>Irrigated</i>					
Control	10.348	10.739	6.588	7.562	8.809
1	11.462	13.612	10.774	11.243	11.773
2	13.142	14.708	11.008	12.745	12.901
3	13.594	13.338	10.881	12.450	12.566
4	13.074	13.290	10.125	12.461	12.238
5	12.593	13.064	9.979	11.460	11.774
Average	12.369	13.125	9.893	11.320	11.677
LSD _{5%}					
Fertilization	0.32	0.99	0.82	0.46	0.35
Irrigation	0.19	0.57	0.47	0.26	0.20

Treatments: 1= 60 kg N + 45 kg P₂O₅ + 53 kg K₂O; 2 = 120 kg N + 90 kg P₂O₅ + 106 kg K₂O; 3 = 180 kg N + 135 kg P₂O₅ + 159 kg K₂O; 4 = 240 kg N+180 kg P₂O₅ + 212 kg K₂O; 5 = 300 kg N + 225 kg P₂O₅ + 265 kg K₂O.

Table 4
Statistical results of maize, without irrigation

Source of variance	SQ	FG	MQ	F-value	Significance level *
Regression	56.5519	2	28.2760	3.660	≈ 0.03
Remainder	718.4927	93	7.7257		

Independent variable	Regression coefficient	Error of coefficient	Standard regression coefficient	t-value	Significance level **
Fertilizer	0.0259	0.0099	0.94	2.63	≈ 0.001

* = in case of one-tailed test; ** = in case of two-tailed symmetric test

The statistical evaluation of the non-irrigated treatments of maize is presented in Table 4: The multiple R-value (0.27) is rather small and the error of estimation is high: 2.779 t/ha. The small R-value does not mean that the quadratic function is inappropriate for the description of the correlation as its validity has been proven by the F-probe at 3% significance level. Based on the t-probe the linear and the quadratic terms are significant at 1% and 2% level, respectively, and their importance is roughly equal.

The statistical evaluation of the irrigated treatments can be seen in Table 5. In the case of irrigated treatments the multiple R-value (0.66) is higher than in the non-irrigated treatments. The accuracy of approximation has improved (1.495 t/ha) and the F-probe indicates that the reliability of the quadratic function fitting is also better. Considering the significant linear and quadratic members of the equation, the linear one is of greater importance.

Table 5
Statistical results of maize, with irrigation

Source of variance	SQ	FG	MQ	F-value	Significance level *
Regression	158.0902	2	79.0451	35.357	≈ 0.00
Remainder	207.9113	93	2.2356		

Independent variable	Regression coefficient	Error of coefficient	Standard regression coefficient	t-value	Significance level **
Fertilizer	0.0417	0.0053	2.19	7.86	≈ 0.00

* = in case of one-tailed test; ** = in case of two-tailed symmetric test

On the basis of the analysis results with several years' yield data it can be concluded that in non-irrigated treatments the approximation with a quadratic function shows a weak or moderately strong correlation between fertilization and yields. The error of estimation is rather big, the reason of which lies with great variations in the yearly harvest, that is, the fluctuation of yields that had not received irrigation. Due to the changeable water supply the effect of fertilization also changes extensively year by year. Under such circumstances the optimum fertilizer dose can only be calculated with decreased reliability. Because of the drought characteristic of the years the effects of the linear, yield increasing, and quadratic, depressing, influences are roughly equal.

With irrigation the differences in annual fertilizer responses of maize have become smaller and the fluctuation of yields has decreased. The R-values show a strong correlation and its reliability was proved by the significance tests. The accuracy of approximation is good. Considering the value of the standardized regression coefficients, the linear, yield increasing influence is of greater im-

portance. The linear part dominates the line of the quadratic curve. Under irrigated conditions the optimum fertilizer dose can be calculated much more precisely and with much greater reliability.

The maximum yields of maize and the corresponding fertilizer rates are presented in Table 6. The experimental results show that the maximum yield can only be achieved with high fertilizer doses. With irrigation the maximum yield is reached at a higher level and, due to the improved efficiency of fertilizers, the need for nutrients hardly increases.

Table 6
Fertilizer dosage for the maximum yield of maize

	N kg/ha X_{\max}	Yield, t/ha Y_{\max}	Growth t/ha	Average fertilizer efficiency, kg/kg
Without irrigation	175	9.682	2.267	13
Irrigated	183	12.992	3.817	21

Table 7
Marginal efficiency of fertilization in maize

	Marginal efficiency 10 kg/kg fertilizer	Yield, t/ha	Growth t/ha	Average fertilizer efficiency, kg/kg
Without irrigation	108	9.344	1.930	18
Irrigated	139	12.772	3.597	26

The fertilizer ratio corresponding to 10 kg grain yield of maize was also calculated to determine the economic dose (Table 7).

When growing maize or a similar genotype without irrigation the fertilizer dose recommended to meet economical criteria is 30-40 kg N/ha less, that is 100-110 kg/ha. In irrigated stands, meaning a higher level of yields, the economical fertilizer dose is also greater (140 kg N/ha) than without irrigation because of the positive irrigation \times fertilization interaction.

In sustainable crop management the environmental protection aspects of agrotechnical elements (such as fertilization) play a very important role. Our long-term experimental data on chernozem soil proved that when higher N doses were used than the optimum rate for wheat some NO_3 and other N-residues remained in different soil layers (Figure 6.). The real environmental hazard is that the accumulated NO_3 amount does not remain in the middle soil layers (80-180 cm of the soil profile) but moves downward to deeper soil layers and to the groundwater (even under the dry climatic conditions of Hungary).

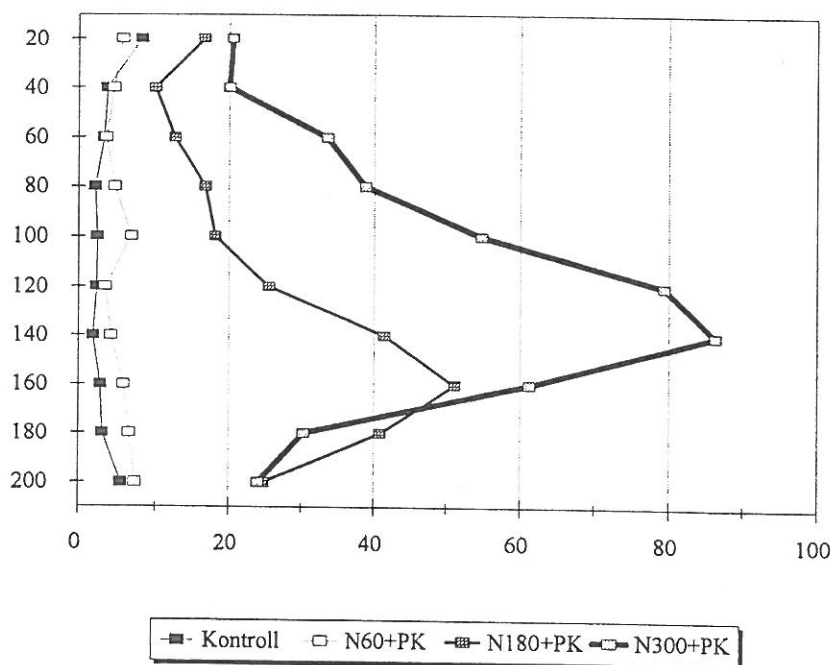


Figure 6
Effect of N fertilizer on the NO_3 -content of chernozem soil

Summary

In a twenty-year long-term experiment the plant nutrition system of cereals (winter wheat, maize) was investigated on chernozem soil under continental climatic conditions.

It was found that the appropriate plant nutrition system, fertilization had a great effect on yield increase, yield stability and the adaptability of maize and winter wheat varieties to ecological and agrotechnical stresses.

According to our long-term experimental data there were differences in soil nutrient - and fertilizer demands and soil nutrient - and fertilizer utilization (mainly in nitrogen) of winter wheat varieties.

Winter wheat varieties could be classified into 4 groups according to their nutrient and fertilizer responses. Our research data proved that the appropriate plant nutrition system did not cause environmental hazards (NO_3 -accumulation in different soil layers).

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